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Original Research Paper

Effect of ball mill grinding parameters of hydrated lime fine grinding on consumed energy

Eyüp Sabah [a,*], Orhan Özdemir [b], Selçuk Koltka [a]

[a] Department of Mining Engineering, Afyon Kocatepe University, 03200 Afyonkarahisar, Turkey
[b] Department of Mining Engineering, Istanbul University, 34320 Avcılar-Istanbul, Turkey

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ABSTRACT

The influence of several grinding parameters such as charged material volume, ball filling ratio, and mill rotation speed on energy efficiency of fine grinding of hydrated lime and the product fineness of hydrated lime was studied experimentally using a laboratory scale ball mill. The product size and surface area of the ground samples were determined with respect to the above variables, and changes in energy input during the grinding were described in detailed. Finally, the optimum conditions for the grinding of the hydrated lime with the ball mill were obtained. The results from this study showed that the ball mill load and mill speed are the most important parameters rather than ball mill charged material volume for the fine grinding of the hydrated lime using the ball mill in terms of energy efficiency associated with external surfaces.

1. Introduction

Mechanical treatment of raw, consumable or prefabricated materials is always a major issue in many industrial productions. Therefore, numerous steps of a wide variety of production methods are necessary to obtain for desired finished material. Recently, in various industrial processes the need for fine particles, especially submicron-sized particles, has significantly increased in field of preparing raw powders. For this reason, many researchers have focused on fine grinding, especially for ultra-fine grinding. In fact, it is an energy intensive stage in the overall process to provide materials in proper fine size range for required properties of final product.

Limestone or calcium carbonate ($CaCO_3$) exists as a natural stone in nature. Limestone in its natural form is a very slow reacting; hence, it has a limited use throughout the world. The most significant use of limestone in agriculture is a finely ground and dry form or in flue gas desulphurization in slurry form. Meanwhile, lime is used in most pollution control application as calcium hydroxide. In order to manufacture calcium hydroxide from limestone, calcium carbonate must be converted to calcium oxide and calcium hydroxide (hydrated lime, [$Ca(OH)_2$]) which is a caustic substance produced by heat treatment of limestone. When this hydration process is done with just the right amount of water is called "Dry Hydration". In this case, the hydrate materials is a dry powder, and its ultra-fine grinding of this material produces unusual properties such as particle size, specific surface area, bulk density, reactivity and whiteness. Further, it is used mainly in sugar refining, paper processing, leather treatment, flue gas treatment, manufacturing of calcium phosphate, paint applications, steel ferro alloys, agricultural applications, soil stabilization, water treatment, construction, pharmaceutical, and masonry applications etc. [1].

In this matter, the objective of this paper is to investigate the effect of the various grinding parameters such as ball charge filling ratio, material charged ratio, and mill speed on the properties of hydrated lime and fineness of the product using a ball mill.

2. Experimental procedure

The hydrated lime powder ($<d_{50} = 297$ μm) used in this study obtained from Adaçal Endüstriyel Mineraller San. Tic. A.Ş., Turkey. The particle size of the hydrated lime samples is less than 1 mm with a wide particle size distribution (Fig. 1). Approximately 21.49% of the sample is under 10 μm. The physical and chemical properties of the hydrated lime powder are also shown in Table 1.

The particle size distribution of the sample was determined using Mastersizer 2000 by Malvern. The SEM pictures of original and ground hydrated lime were obtained using a Zeiss Evo LS 10 microscope. The density of hydrated lime was measured by Ultrapycnometer Quantachrome 1000. The bulk density and activation coefficient were determined according to TS EN 459-2 [2] and TS EN 459-1 [3], respectively. Datacolor Elrepho was used to measure

* Corresponding author. Tel.: +90 272 2281423x1320; fax: +90 272 2281422.
E-mail address: esabah@aku.edu.tr (E. Sabah).

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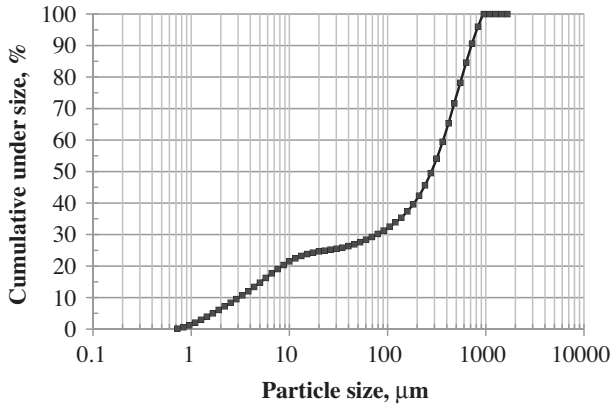

Fig. 1. Particle size distribution of the feed after the grinding using the ball mill.

Table 1
Physical properties of the hydrated lime.

d_{97} (μm)	853
Median size of the feed (d_{50}) (μm)	297
Density (g/cm^3)	2.24
Bulk density (kg/m^3)	690
Whiteness (%)	92.98
Spesific surface area (m^2/g)	0.54
Activation	74.6

the whiteness of the products. The specific surface area of the feed and the ground products based on weight was calculated from the data of particle size distribution, where the shape of the ground product particles is assumed to be spherical according to the following equation:

$$S_w = \frac{6\sum \frac{v_i}{d_i}}{\rho_i \sum v_i} = \frac{6}{\rho_i D_{[3,2]}} \quad (1)$$

where S_w is the specific surface area based on weight, V_i is the relative volumes in the size class i, d_i is the mean size class diameter, and ρ_i is the particle density, $D_{[3,2]}$ is the surface weighted or sauter mean diameter which is reproduced from the results of particle size using analyzer software (Malvern Master Sizer 2000 ver 5.54). Garcia et al. [4] and Cho et al. [5] showed a direct comparison of the BET method and particle size analysis on the specific surface area. The linear relationship, which can be seen from the grinding periods increasing, suggests that the particle size analysis is a reliable method for evaluation of the ground products.

A laboratory scale batch mill made of stainless steel with an inside diameter of 200 mm and an inner volume of 5000 cm^3 was used for the grinding processes. In addition, the grinding ball is also made of steel. It was thought that highest collision energy could be obtained if the balls at different diameters were used [6]. For this reason, three different ball diameters ranging between 12–14–16 mm were used for the grinding. The total weight of the balls for each value of ball filling ratio was 9.5 kg for 25%, 11.4 kg for 30%, 13.3 kg for 35%, and 15.2 kg for 40% by volume feed masses. And, the weight of the materials for each value of charged volume ratio was 2.8 kg for 25%, 3.36 kg for 30%, 3.92 kg for 35%, and 4.48 kg for 40%. The rotational speeds of the mill were set at 29, 59, 69, 79, 84 rpm which are approximately 50%, 60%, 70%, 80%, 85% of the critical speed, respectively. In order to investigate the effects of mill charge volume, ball filling and mill speed on the grinding power consumption was set at 45 min as a grinding time. The specifications for the grinding media and experimental conditions are presented in Table 2.

Table 2
Summary of the experimental conditions.

Item	Experimental conditions
Rotation speed (rpm)	49, 59, 69, 79
Ball filling ratio (%)	30, 35, 40
Ball size (mm)	12, 14, 16
Material charged volume (ml)	25, 30, 35, 40

The energy consumed by the mill in dry grinding experiments of the hydrated lime was measured by a MPR-53S-DIN digital multimeter, (ENTES Co., Turkey). In this study, only the active power (kW) was recorded and used by considering the power factor. The active power of the mill is sensitive to the current change at all levels up to the rated power of the motor. An active power reading was recorded for each minute during each grinding pass, and about 10 readings were done for each pass. The mean active power of each pass was regarded as its real one. The mean active power, P_{mn} (kW), of the nth pass for the grinding experiments was determined by:

$$P_{mn} = \frac{\sum_{i=1}^{m} P_{ni}}{m} \quad (2)$$

where P_{ni} is the ith discrete power reading of the nth pass, and m is the number of readings of the nth pass. In order to evaluate the net energy consumption of the mill, the mass specific energy consumption, E_m (kWh/kg), was determined by:

$$E_m = \frac{P \cdot t}{M} \quad (3)$$

where M (kg) is the mass of the grinding material feed to ball mill, and t (h) is the grinding time.

Energy efficiency or energy utilization, η (m^2/Wh), which is defined as the increment of specific surface area per unit of specific energy consumption [7], was calculated by:

$$\eta = \frac{\Delta S}{E_m} \quad (4)$$

where $\Delta S = S - S_0$, S and S_0 are the specific surface areas (m^2/g) of the ground product and the feed, respectively.

The grindability of the hydrated lime for each milling parameter was calculated from the following equation [8],

$$\text{Grindability} = \frac{\frac{d_F}{d_{50}}}{E_m} \quad (5)$$

where d_F and d_{50} are the median size of the feed (μm) and the product, respectively.

3. Results and discussion

Fig. 2 shows the particle size distribution of the hydrated lime (−1 mm feed) ground in the dry ball mill obtained at various operational parameters. The median diameter of the feed material is about 297 μm, but this value shifted from the right side to left during the grinding. It was observed that an increase in the grinding time not only produced finer sizes products but also narrowed the particle size distribution by reducing the size and fraction of coarse particles. With the particles coarser than 10 μm, low charged material volume and high mill speed are effective, where similar effect could be achieved with high ball charge. At 79 rpm mill speed, 40% ball charge, 25% charged material volume, and 45 min grinding period, the hydrated lime micronization was developed more harmonious distribution curves.

Fig. 3 shows the relationship between the grinding energy consumed and median diameter for each combination of various oper-